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RESEARCH MEMORANDUM

FREE-FLIGHT INVESTIGATION

TO DETERMINE SOME EFFECTS OF TAIL DAMPING AND WING-TAIL

INTERFERENCE ON THE ROLLING EFFECTIVENESS OF AILERONS

AND A SPOILER ON A MODIFIED-DELTA WING AT MACH

NUMBERS FROM 0.6 TO 1.5

By Roland D. English

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
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SUMMARY

An investigation has been made to determine some effects of tail damping and wing-tail interference on the rolling effectiveness of ailerons and a spoiler on a modified-delta wing. The investigation was made by means of free-flight models at 0° angle of attack and 0° angle of sideslip over a range of Mach numbers from 0.6 to 1.5. The results indicate that adding tail surfaces to a wing-body combination appreciably reduced the rolling effectiveness of a 1/3-exposed-span inboard aileron, a 2/3-exposed-span inboard aileron, and a 2/3-exposed-span inboard spoiler, but caused negligible change in the rolling effectiveness of a 1/3-exposed-span midspan aileron. Changing the location of the horizontal tail from the plane of the wing to 40 percent of the wing root chord above the plane of the wing caused a further reduction in the rolling effectiveness of the 2/3-exposed-span aileron at subsonic speeds and the 2/3-exposed-span spoiler at both subsonic and supersonic speeds.

INTRODUCTION

The importance of including the effects of tail damping and wing-tail interference in investigations of rolling effectiveness of lateral controls has been shown previously in reference 1. The data of reference 1 were limited to ailerons, however, and were limited as to the tail locations investigated in an effort to alleviate the effects of downwash also. It is the purpose of this investigation to determine some effects of tail damping and wing-tail interference on the rolling effectiveness of both ailerons and spoilers and to determine the effect of moving the

horizontal tail from the plane of the wing to an appreciable distance above the plane of the wing. The investigation was made at 0° angle of attack and 0° angle of sideslip over a range of Mach numbers from 0.6 to 1.5.

SYMBOLS

b   wing span, ft

c   wing chord, ft

c_r wing root chord at body center line, 1.416 ft

M   Mach number

p   rolling velocity, radians/sec

R   Reynolds number

V   velocity of model along flight path, ft/sec

pb/2V   wing-tip helix angle, radians

Δ(pb/2V)   change in pb/2V due to a change in model geometry

DESCRIPTION OF MODELS

The models of this investigation consisted of modified-delta wings on cylindrical bodies with ogive noses and with tails which were free to roll relative to the body so as to provide longitudinal and directional stability without causing resistance to roll. The wings had an aspect ratio of 3.150, a semispan of 1.114 feet, and were swept back 55° at the leading edge and 10° at the trailing edge. Seven of the models were equipped with plain, trailing-edge ailerons differentially deflected. The deflection of each aileron was 5°. Three models were equipped with spoilers located 0.375 inch forward of the trailing edge. The aileron chord was $0.100c_r$ and the spoiler height was $0.022c_r$.

In order to determine the effect of adding tail surfaces to the configuration, six of the models were equipped with fixed horizontal and vertical tail surfaces of the same plan form as the wing. The area of the horizontal tail was 25 percent of the wing area and the semispan was one-half the wing semispan. The area of the vertical tail was 25 percent of the wing area and the height of the vertical tail was 70.7 percent of

the wing semispan. On four models the horizontal tail was located in the plane of the wing. On two of the models the horizontal tail was located $0.400c_r$ above the plane of the wing. It should be noted that the free-to-roll tails mentioned previously had negligible resistance to roll; the models without fixed tail surfaces were, therefore, effectively wing-body combinations and are herein after referred to as models with no tails.

The wings of the models were machined from solid aluminum alloy and had an NACA 65A003 airfoil section. The tail surfaces were of 1/8-inch aluminum-alloy flat plate with rounded leading edges. The physical characteristics and dimensions of the models are given in tables I and II and in the photographs of figure 1 and in the sketches of figure 2.

TESTS

The tests were made at the Langley Pilotless Aircraft Research Station at Wallops Island, Va. A two-stage rocket was used to propel the models to a Mach number of about 1.5. Test data were recorded continuously during a period of free flight following burnout of the second propulsion stage. A spinsonde (polarized radio transmitter) was used to measure rolling velocity. Model flight-path velocity, range, and altitude were measured by means of radar. Atmospheric data and wind velocity were obtained just prior to each test by means of radio equipment carried aloft by balloons which were tracked by radar. The range of test Reynolds numbers is shown in figure 3.

ACCURACY AND CORRECTIONS

It is estimated that the test data are accurate within the following limits:

	Subsonic	Supersonic
$pb/2V$, radians	±0.003	±0.001
M	±0.01	±0.01

The data were corrected by the method of reference 2 for the wing and tail incidence errors resulting from construction tolerances. No correction was made for the effects of rolling moment of inertia since, at the rolling accelerations incurred in these tests, reference 3 shows these effects to be negligible.

RESULTS AND DISCUSSION

Effect of Adding Fixed Tail Surfaces

The effect on $pb/2V$ of adding fixed tail surfaces to the configuration is shown in figure 4 where the variation of $pb/2V$ with Mach number is presented for the various controls with and without fixed tail surfaces on the body. Parts of some of the $pb/2V$ curves are omitted because some of the models incurred a longitudinal or directional trim change in the transonic region which may have affected rolling effectiveness. Sufficient data were obtained from all models to get an indication of the effect of adding the tail, however. With the exception of the midspan aileron, addition of the tail surfaces caused an appreciable reduction in $pb/2V$ for each of the controls investigated at both subsonic and supersonic speeds. Part of this reduction was, of course, due to the additional damping in roll of the tail surfaces excluding the effect of wing-tail interference. The increase in roll damping due to the addition of the tail surfaces, which were of the same plan form as the wing, was easily evaluated by taking into accout the difference in body effects by the method of reference 4. The increase in damping was found to be about 17 percent which is not sufficient to account for the total reduction in $pb/2V$ shown in figure 4. The remaining reduction is attributed to wing-tail interference. The effect of wing-tail interference is in some cases appreciable, particularly for the $1/3$-exposed-span inboard aileron where it was sufficient to cause roll reversal at a Mach number of about 1.09.

Comparison of the reduction in $pb/2V$ due to wing-tail interference for the various ailerons is shown in figure 5. The reduction in $pb/2V$ due to interference effects is considerable over the entire test Mach number range for the $1/3$-exposed-span inboard aileron. For the $2/3$-exposed-span inboard aileron the reduction is much smaller. In the case of the $1/3$-exposed-span midspan aileron, wing-tail interference slightly increases $pb/2V$ or causes no significant change at all. The reasons for these varied effects may be seen by examining the action on the tail surfaces of the velocity components induced by the wing loads (downwash and sidewash). In the area directly behind the aileron, the vertical component of induced velocity is in such a direction that it opposes the aileron or tends to reduce $pb/2V$. Inboard and outboard of the aileron the induced velocity, though much smaller than that directly behind the aileron, is in such a direction that it tends to aid the aileron or increase $pb/2V$. On the models of this investigation, the span of the horizontal tail was about equal to the spanwise extent of the $1/3$-exposed-span inboard aileron. The tail was therefore in a region of high adverse interference effects for both of the inboard ailerons. In the case of the $2/3$-exposed-span aileron, about one-half of the aileron load was outboard of the tail, however, and the velocity induced at the tail by this part of

the load counteracted the velocity induced by the part of the load directly ahead of the tail. Also, since $pb/2V$ was higher for the 2/3-exposed-span aileron, the wing damping load and the velocity induced by this load was higher for this model than for the 1/3-exposed-span-aileron models. Since the velocity induced by the damping load was in a favorable direction, the adverse effects of the velocity induced by the aileron load were still further reduced for the 2/3-exposed-span aileron. In the case of the 1/3-exposed-span midspan aileron, the tail was almost entirely inboard of the aileron. The velocity induced at the tail by the aileron load, as well as that induced by the wing damping load, was in a favorable direction; hence, $pb/2V$ was slightly increased. The horizontal component of velocity (side-wash) was in an adverse direction for all ailerons, and was largest for the 2/3-exposed-span aileron and smallest for the 1/3-exposed-span midspan aileron. The effects of sidewash were small in comparison with the effects of downwash, however.

The effects of wing-tail interference are compared for an aileron and a spoiler in figure 6. Both were 2/3-exposed-span inboard controls. The loss in $pb/2V$ due to interference was much larger for the spoiler than for the aileron at subsonic speeds and slightly larger at supersonic speeds. It should be noted, however, that although the two controls are of the same spanwise extent, the rolling effectiveness of the spoiler is approximately twice that of the aileron. If the two controls were compared on a basis of equal rolling effectiveness, the loss in $pb/2V$ of the spoiler would be approximately halved, in which case the loss in rolling effectiveness due to wing-tail interference would be about equal for the two controls at subsonic speeds and slightly less for the spoiler at supersonic speeds.

Effect of Moving the Horizontal Tail Out of

the Plane of the Wing

Two models were tested with the horizontal tail placed $0.400c_r$ above the plane of the wing to determine some effects on wing-tail interference of moving the tail location out of the plane of the wing. The results are presented in figure 7. Moving the tail to the new position resulted in a reduction in rolling effectiveness except for the aileron at supersonic speeds where there was no change in $pb/2V$. There are three possible causes for the reduction in $pb/2V$ with change in tail location:

(1) When the horizontal tail was in the plane of the wing, a large part of the tail area was blanketed by the model fuselage, whereas, in the high location, the entire tail was exposed. It is certain that the damping moment of the entirely exposed tail was higher than that of the partially covered tail.

(2) Although the magnitude of the downwash was probably smaller on the tail in the high position, it is possible that the effects of down-wash were stronger since all the tail area was exposed.

(3) The end-plate effect of the horizontal tail mounted on the tip of the vertical tail probably increased the effects of vertical-tail damping and sidewash.

<center>Comparison With Theory</center>

The theories available for predicting the loads due to spoilers at the time of this writing were practically all empirical and were limited in scope. For this reason, no attempt was made to calculate rolling effectiveness for comparison with the spoiler data. Calculations were made for comparison with the aileron data by the following methods: At subsonic speeds, the wing loadings were calculated by the lifting-line method, a method which replaces the wing with a system of horseshoe vortices centered at the quarter-chord line and equates the downwash angle induced by these vortices at the three-quarter-chord line to the effective angle of attack of the wing. At supersonic speeds, the wing loads were calculated by the two-dimensional-strip theory of reference 2. Downwash and sidewash angles were calculated at both subsonic and super-sonic speeds by the method of reference 5. This method is applicable at subsonic speeds and it is shown in reference 6 that downwash at infinity is independent of Mach number and that downwash at infinity is a good approximation of downwash a finite distance behind the wing, at super-sonic speeds. Tail loads were calculated in all cases by the same method used to calculate wing loads. The presence of the body was accounted for by the method of reference 4. No correction was made in the calculations for aeroelastic effects inasmuch as the model wings were relatively stiff and aeroelastic effects were small.

A comparison of calculated and experimental rolling effectiveness is made in figure 8. The agreement between calculations and experimental data is inconsistent. In some cases, in particular for the 1/3-exposed-span midpsan aileron, good agreement was obtained. In other cases, the calculations underestimated experiment by as much as 30 percent.

A comparison of the change in $pb/2V$ due to addition of the tail surfaces as shown by experimental data and predicted by calculations is shown in figure 9(a). Calculations are in fair agreement with experiment at subsonic speeds but in poor agreement at supersonic speeds. In fig-ure 9(b) a comparison is made between experiment and theory of the change in $pb/2V$ caused by moving the horizontal tail to the high location. Agreement is poor at subsonic speeds but good at supersonic speeds.

CONCLUSIONS

The results of an investigation to determine some effects of tail damping and wing-tail interference on the rolling effectiveness of ailerons and a spoiler on a modified-delta wing indicate the following:

1. The addition of tail surfaces to a wing-body combination considerably reduced the rolling effectiveness of 1/3-exposed-span and 2/3-exposed-span inboard ailerons, but did not appreciably change the rolling effectiveness of a 1/3-exposed-span midspan aileron.

2. When compared on the basis of equal rolling effectiveness, the loss in rolling effectiveness due to the addition of tail surfaces was about the same for a 2/3-exposed-span inboard spoiler and the 2/3-exposed-span inboard aileron at subsonic speeds and slightly less for the spoiler at supersonic speeds.

3. Changing the location of the horizontal tail from the plane of the wing to a position 40 percent of the wing root chord above the plane of the wing caused a further reduction in rolling effectiveness for both the 2/3-exposed-span aileron and the 2/3-exposed-span spoiler at subsonic speeds and for the spoiler at supersonic speeds.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 28, 1957.

REFERENCES

1. English, Roland D.: Free-Flight Investigation To Determine Some Effects of Tail Damping and Wing-Tail Interference on the Rolling Effectiveness of Inboard and Outboard Ailerons on an Untapered Sweptback Wing. NACA RM L54L17a, 1955.

2. Strass, H. Kurt, and Marley, Edward T.: Rolling Effectiveness of All-Movable Wings at Small Angles of Incidence at Mach Numbers From 0.6 to 1.6. NACA RM L51H03, 1951.

3. Sandahl, Carl A., and Marino, Alfred A.: Free-Flight Investigation of Control Effectiveness of Full-Span 0.2-Chord Plain Ailerons at High Subsonic, Transonic, and Supersonic Speeds To Determine Some Effects of Section Thickness and Wing Sweepback. NACA RM L7D02, 1947.

4. Spreiter, John R.: The Aerodynamic Forces on Slender Plane- and Cruciform-Wing and Body Combinations. NACA Rep. 962, 1950. (Supersedes NACA TN's 1897 and 1662.)

5. Diederich, Franklin W.: Charts and Tables for Use in Calculations of Downwash of Wings of Arbitrary Plan Form. NACA TN 2353, 1951.

6. Mirels, Harold, and Haefeli, Rudolph C.: Line-Vortex Theory for Calculation of Supersonic Downwash. NACA Rep. 983, 1950.

TABLE I.- MODEL PHYSICAL CHARACTERISTICS

Body:
  Diameter, in. 5.00
  Length, in. 63.87
  Fineness ratio 12.77

Wing:
  Span, in. 26.74
  Chord at center line, in. 16.98
  Area, sq in. 227.02
  Aspect ratio 3.15
  Sweep angle, leading edge, deg 55.00
  Sweep angle, trailing edge, deg 10.00
  Thickness ratio 0.03

Aileron:
  Chord, in. 1.70

Spoiler:
  Height, in. 0.38

Horizontal tail:
  Span, in. 13.37
  Chord at center line, in. 8.49
  Area, sq in. 56.80
  Aspect ratio 3.15
  Sweep angle, leading edge, deg 55.00
  Sweep angle, trailing edge, deg 10.00
  Thickness, in. 0.13

Vertical tail:
  Height, in. 9.45
  Chord at center line, in. 12.00
  Area, sq in. 56.80
  Aspect ratio 3.15
  Sweep angle, leading edge, deg 55.00
  Sweep angle, trailing edge, deg 10.00
  Thickness, in. 0.13

TABLE II.- CONTROL CHARACTERISTICS

Model	Inboard end of control, percent $b/2$	Outboard end of control, percent $b/2$	Horizontal-tail location
1/3-exposed-span inboard aileron			
1	18.7	45.8	None
2			Center line
2/3-exposed-span inboard aileron			
3	18.7	73.0	None
4			Center line
5			$0.400c_r$ above center line
1/3-exposed-span midspan aileron			
6	45.8	73.0	None
7			Center line
2/3-exposed-span inboard spoiler			
8	18.7	73.0	None
9			Center line
10			$0.400c_r$ above center line

Handwritten margin notes:

$P\frac{b}{2V}$

$M = 1.2$

.013
-.002

.028
.022
.022

.017
.017

.071
.051
.038
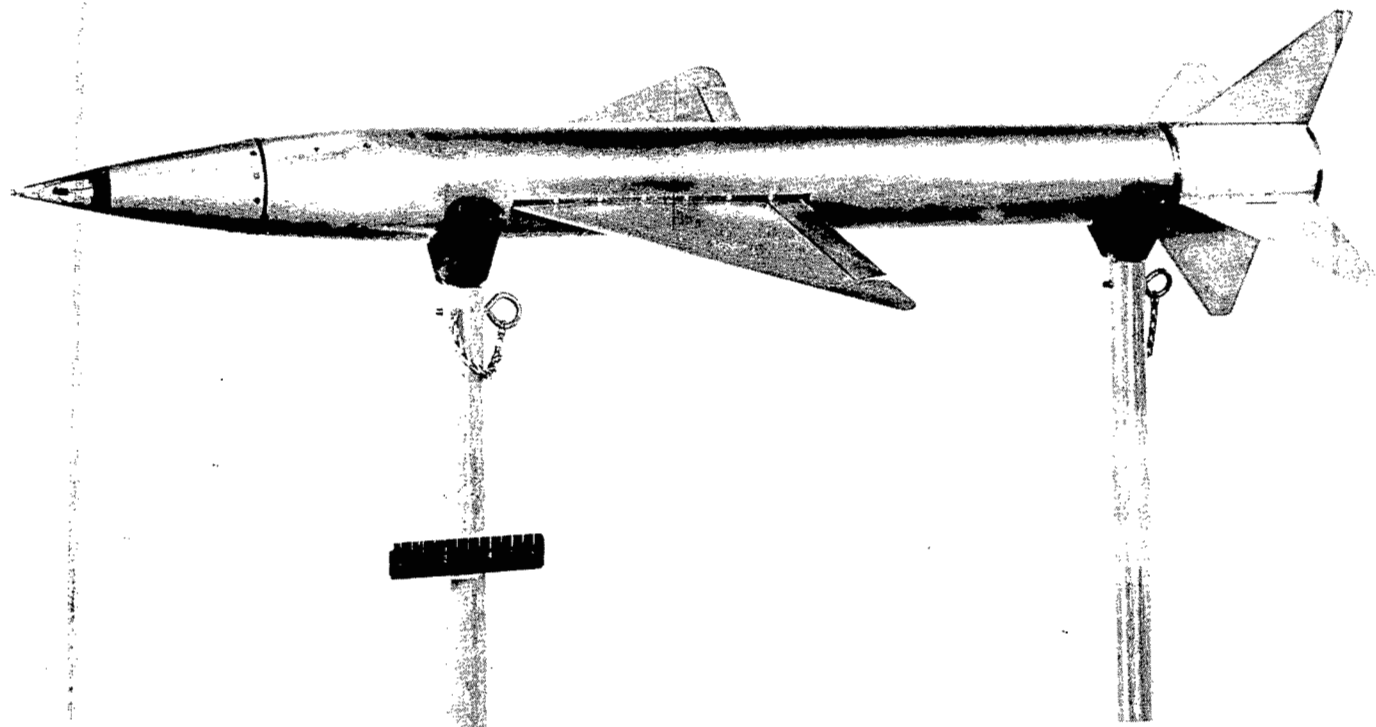
(a) 2/3-exposed-span inboard aileron; no fixed tail fins.   L-90179.1

Figure 1.- Photographs of typical models.
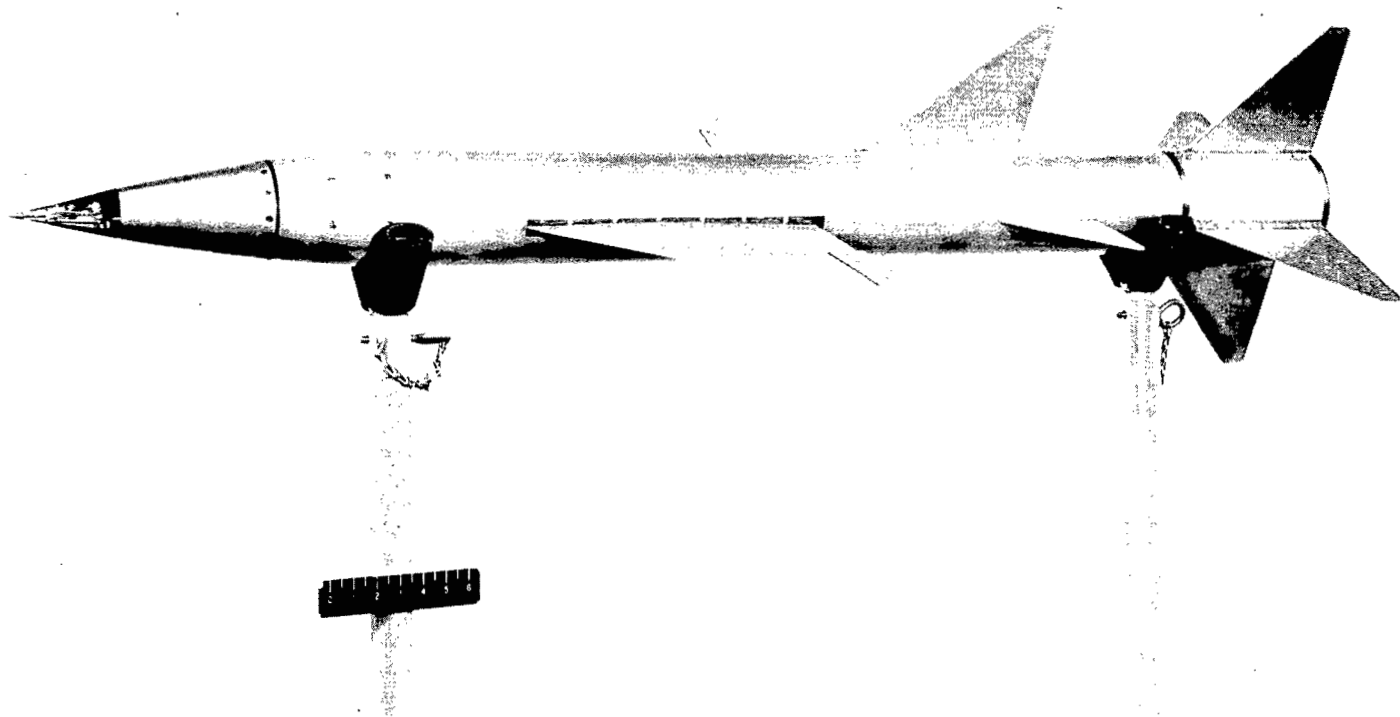
(b) 1/3-exposed-span midspan aileron; horizontal tail on model center line.   L-90114.1

Figure 1.- Continued.
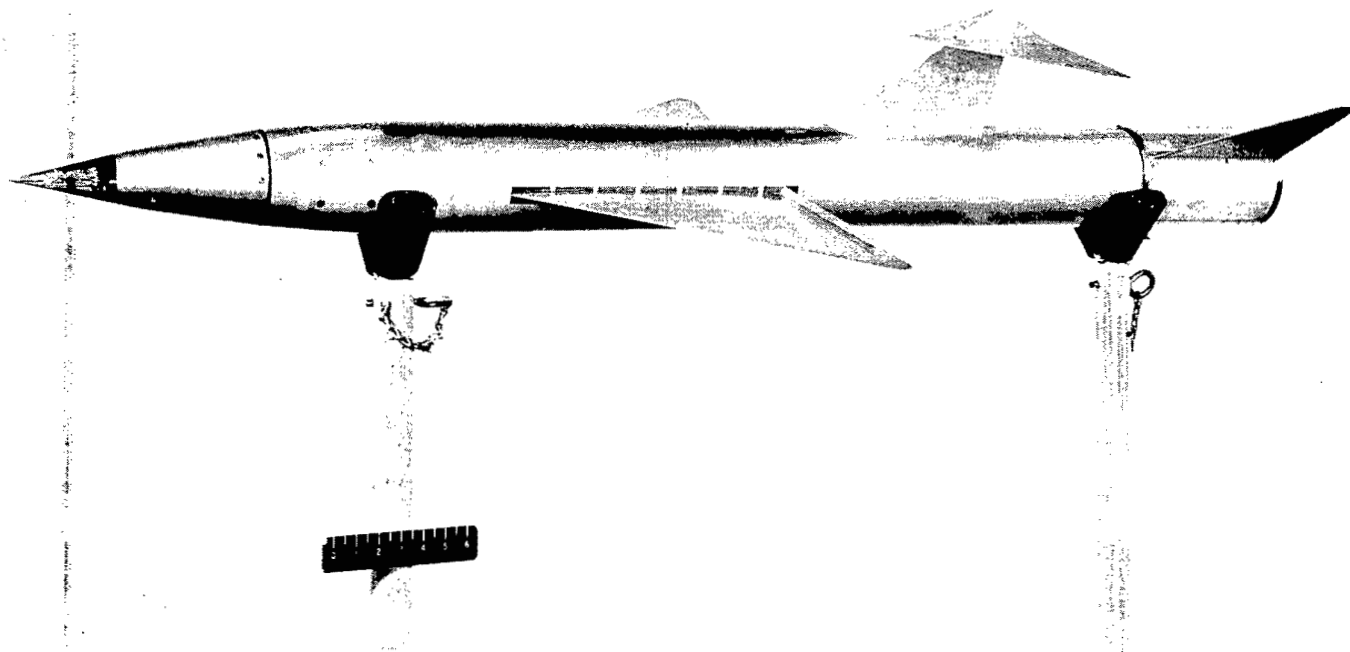
(c) 2/3-exposed-span inboard spoiler; horizontal tail 0.400c_r above center line.   L-90116.1

Figure 1.- Concluded.

No fixed tail (top view)

Horizontal tail on center line
(top view)

Horizontal tail 0.400 c_r above center line
(side view)
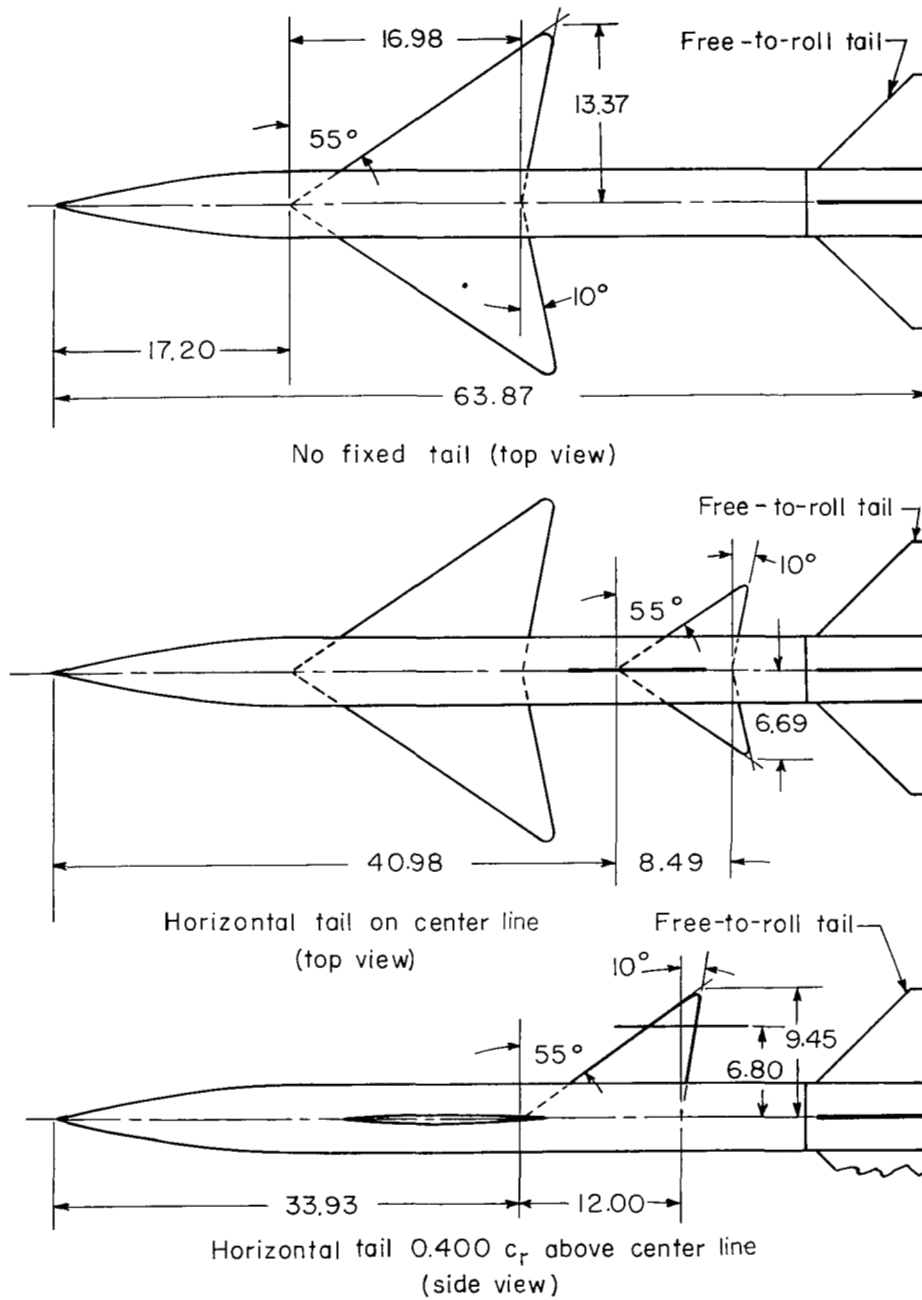
(a) Configurations tested.

Figure 2.- Sketches of test models. All linear dimensions in inches.
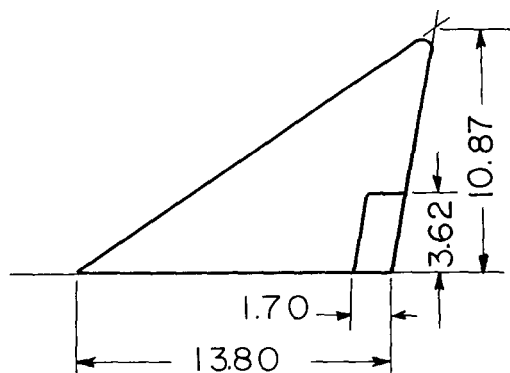
1/3 - exposed - span
inboard aileron
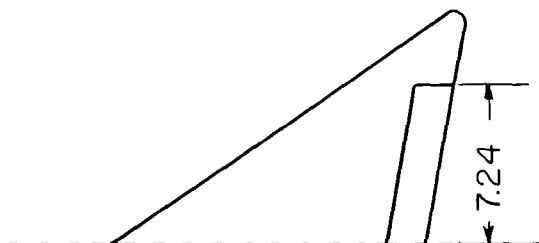
2/3 - exposed - span
inboard aileron
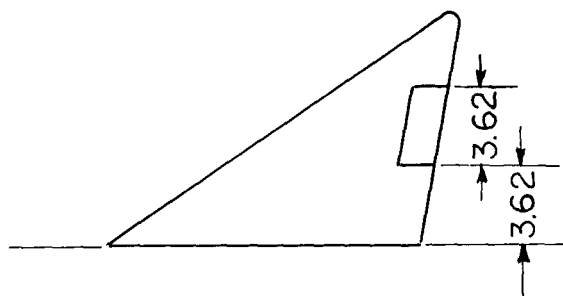
1/3 - exposed - span
midspan aileron
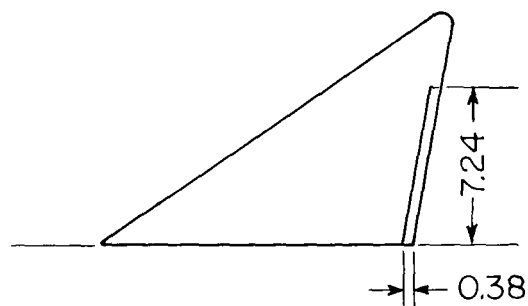
2/3 - exposed - span
inboard spoiler

(b) Control details.

Figure 2.- Concluded.
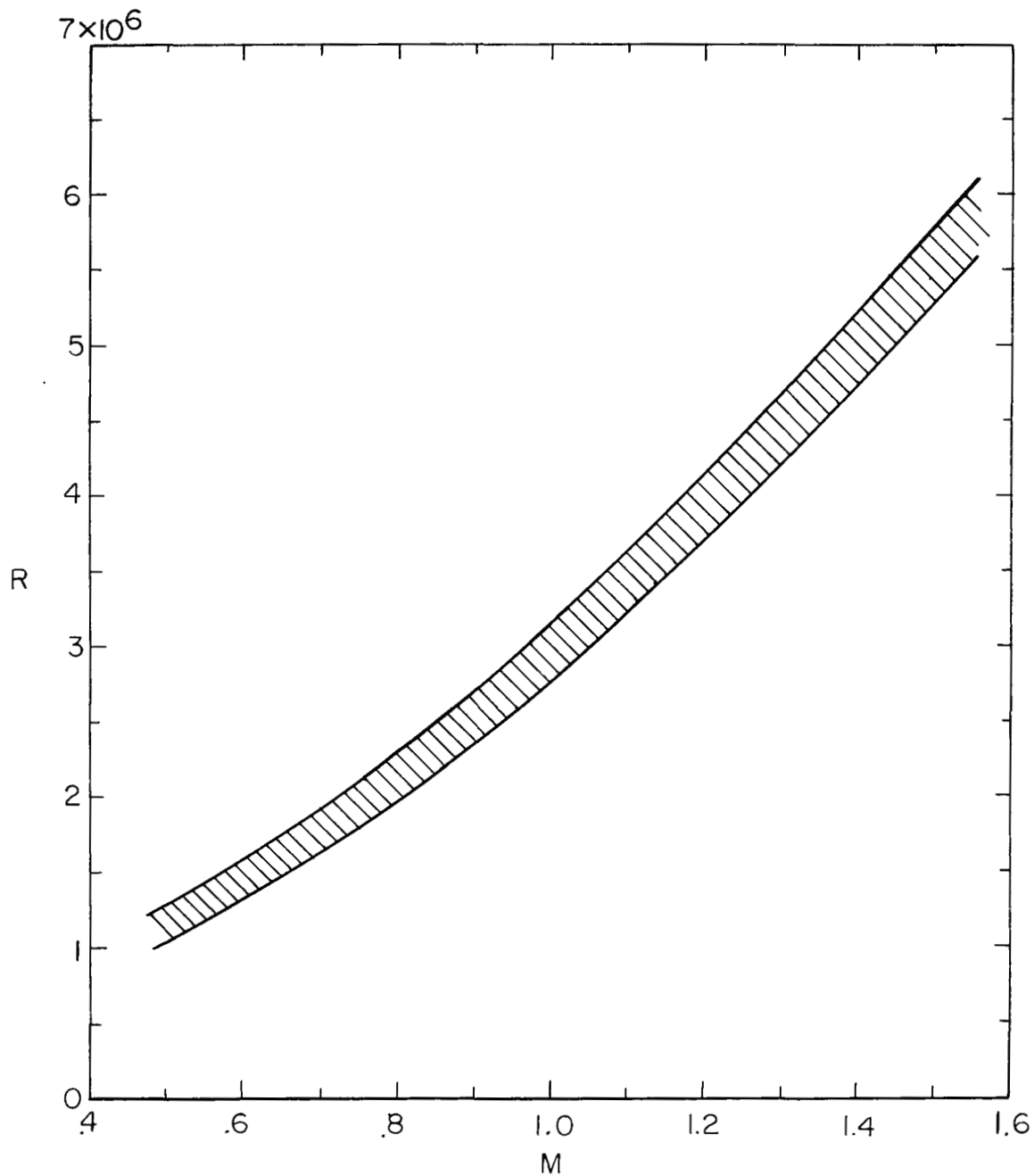
Figure 3.- Variation of Reynolds number with Mach number. Reynolds number based on mean exposed wing chord, 0.575 foot.
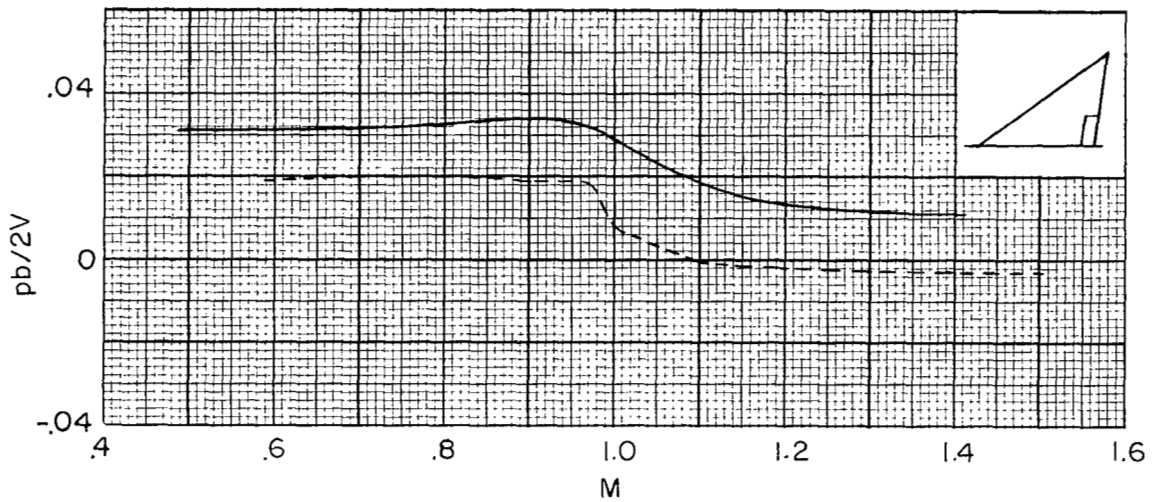
(a) 1/3-exposed-span inboard aileron.
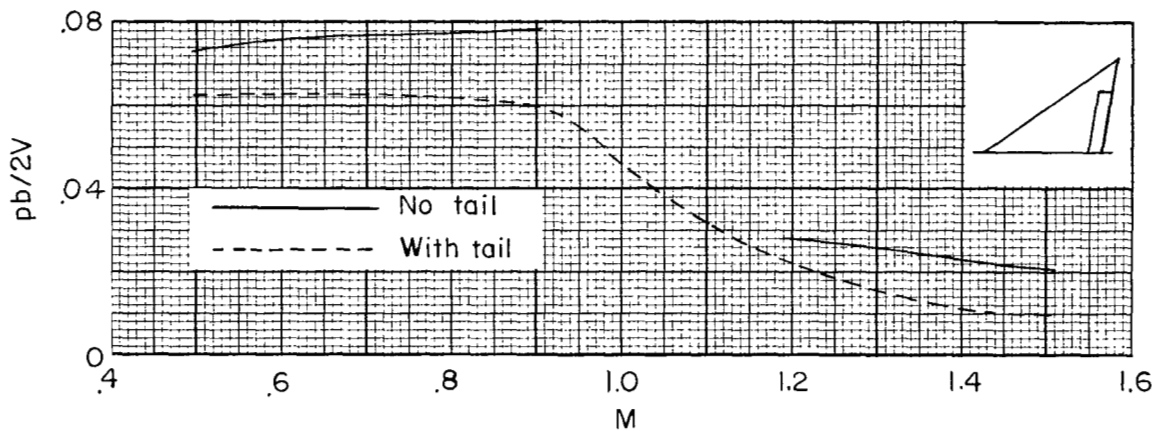
(b) 2/3-exposed-span inboard aileron.

Figure 4.- Effect on pb/2V of adding fixed tail surfaces to the configuration.
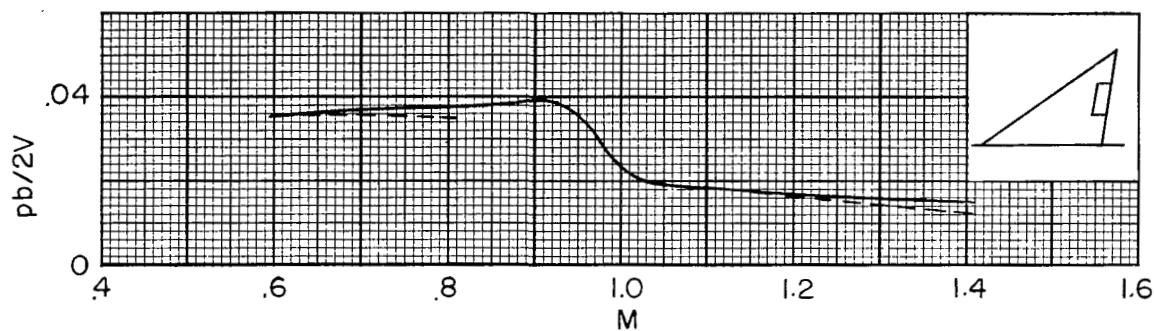
(c)   1/3-exposed-span midspan aileron.
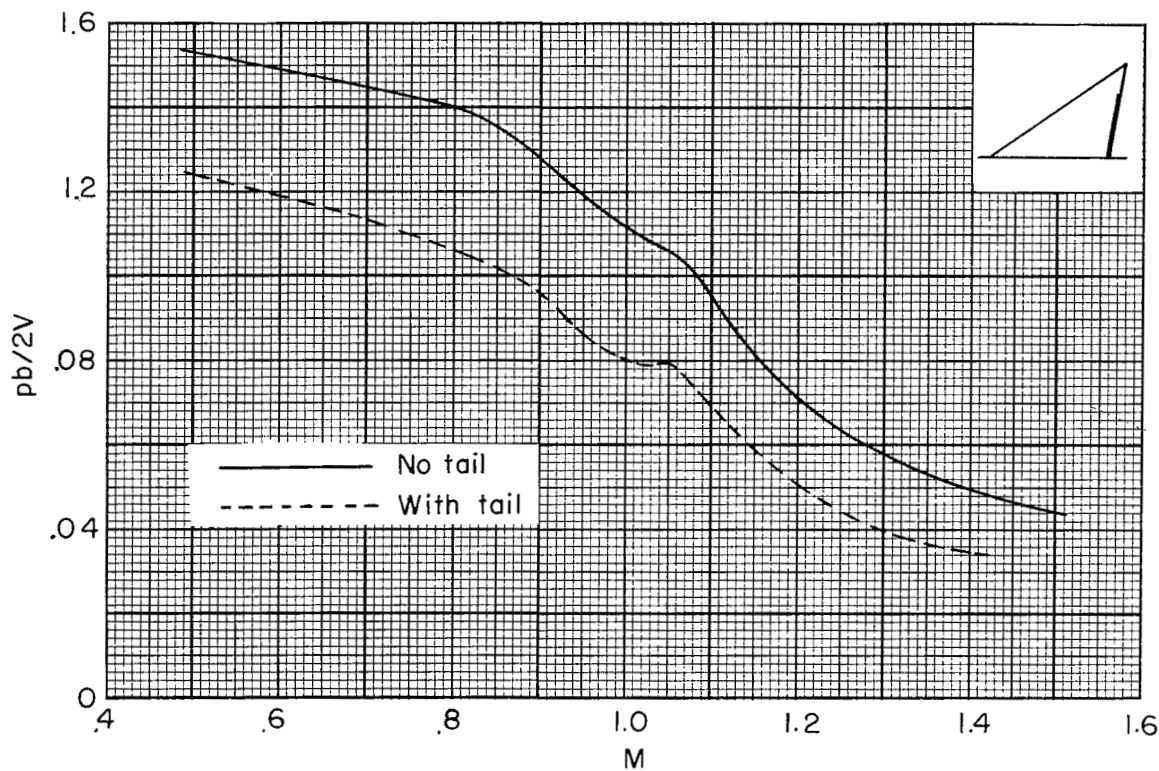
(d)   2/3-exposed-span inboard spoiler.

Figure 4.- Concluded.
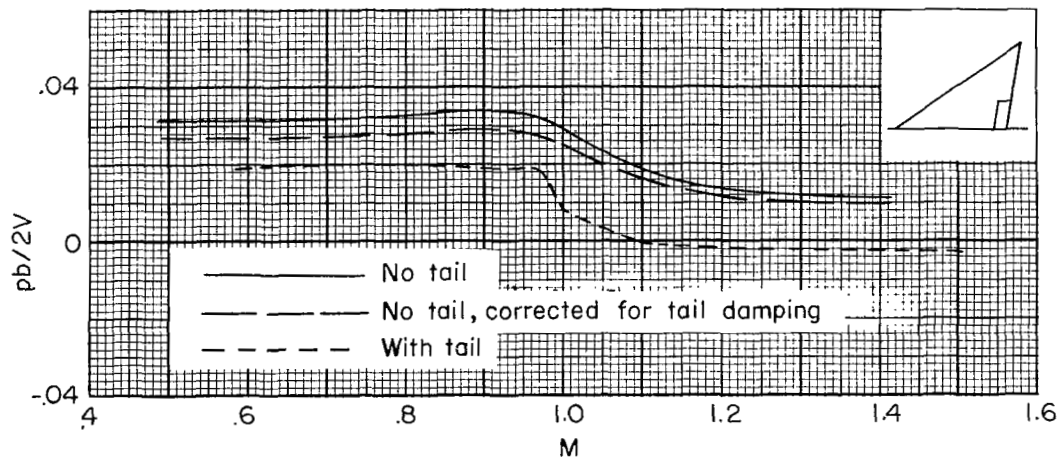
(a) 1/3-exposed-span inboard aileron.
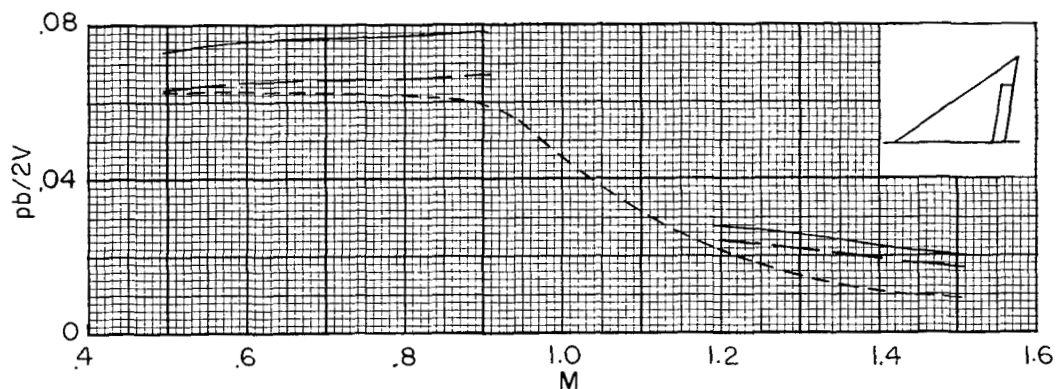
(b) 2/3-exposed-span inboard aileron.
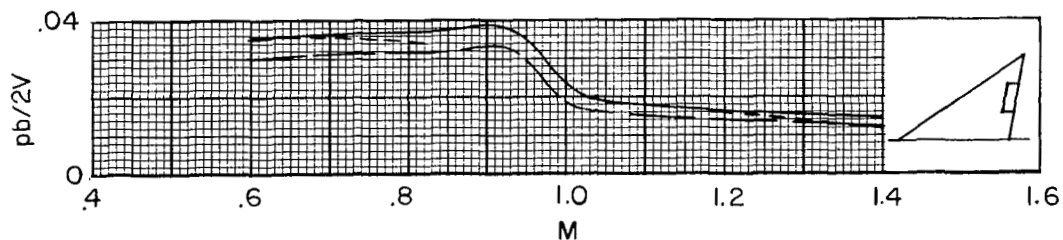
(c) 1/3-exposed-span midspan aileron.

Figure 5.- Comparison of reduction in pb/2V due to wing-tail inter-
ference for the various ailerons.

CONFIDENTIAL
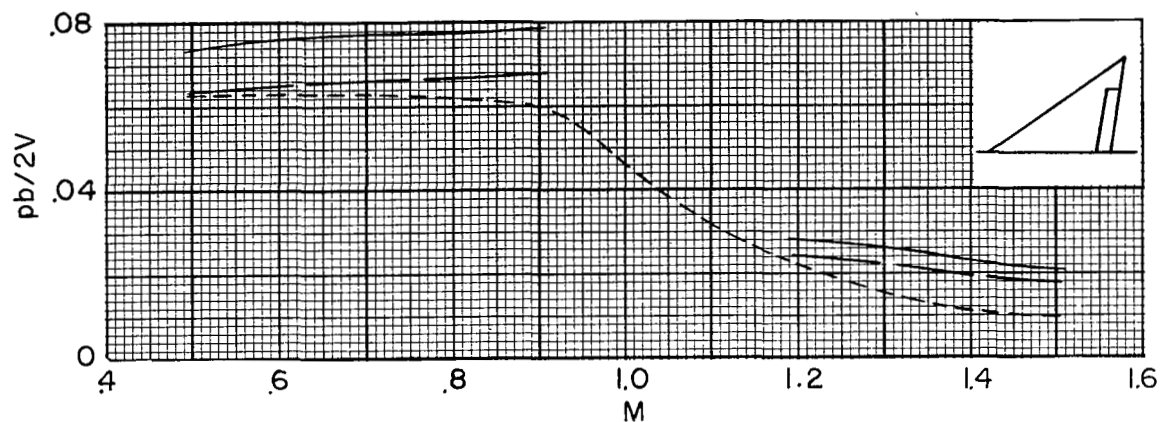
(a) 2/3-exposed-span inboard aileron.
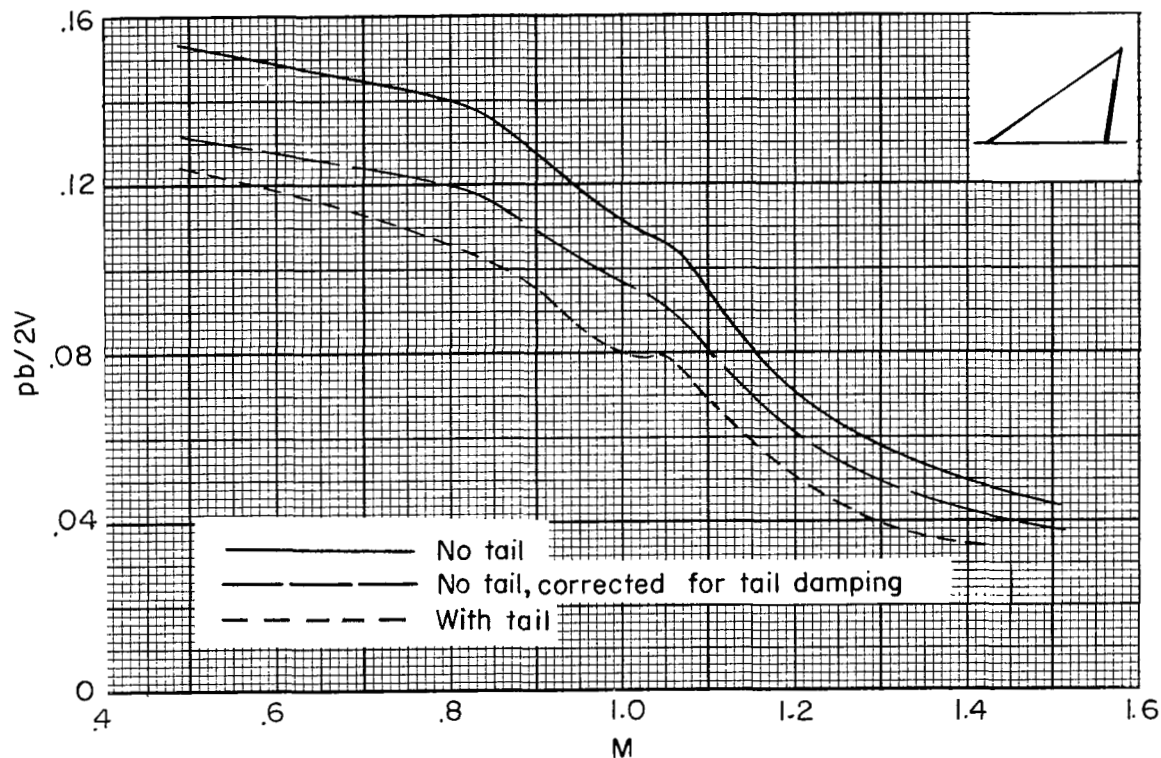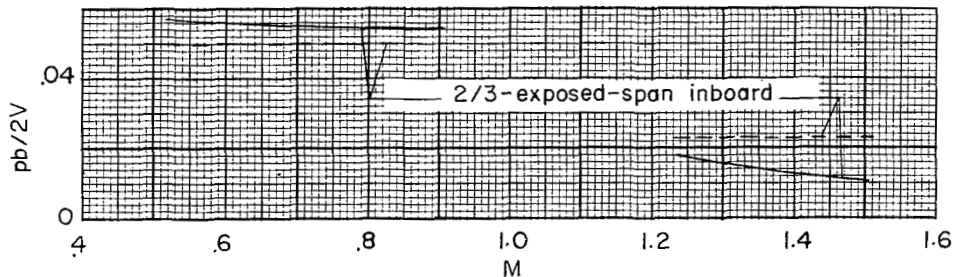

(b) 2/3-exposed-span inboard spoiler.

Figure 6.- Comparison of wing-tail interference for an aileron and a spoiler.
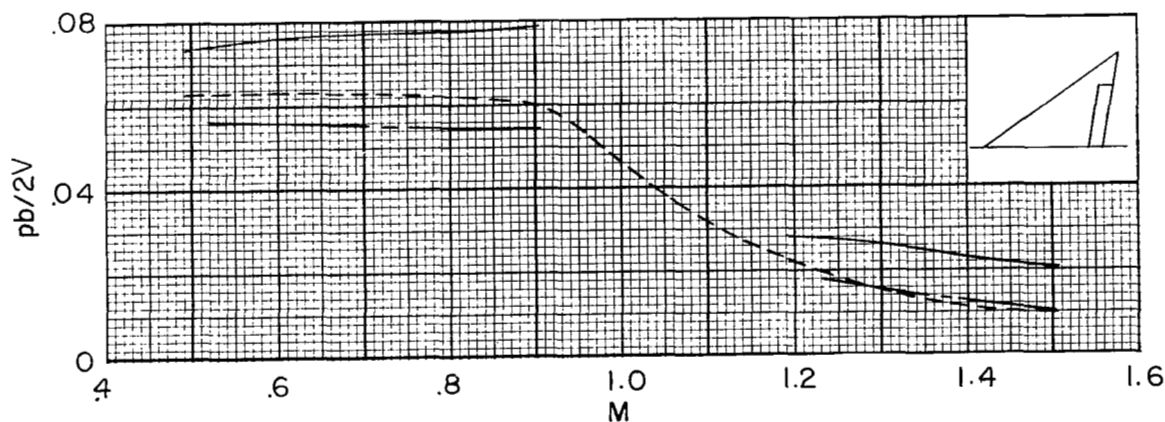
(a)   2/3-exposed-span inboard aileron.
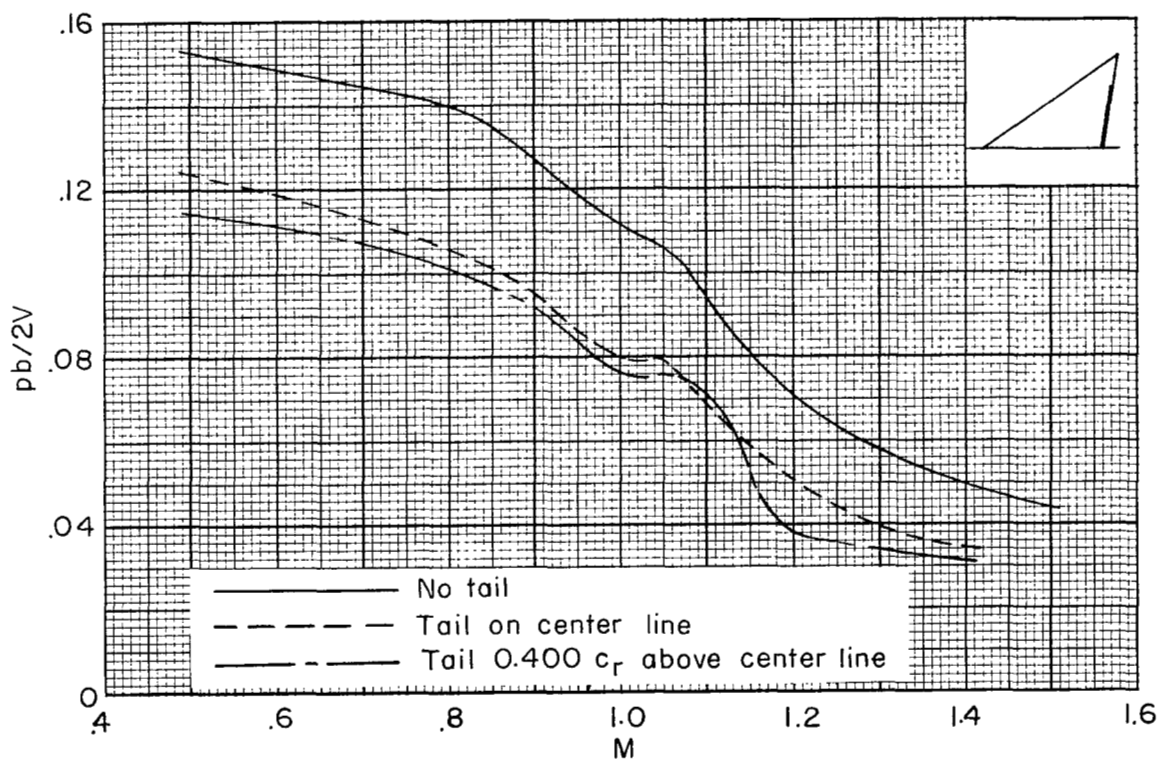
(b)   2/3-exposed-span inboard spoiler.

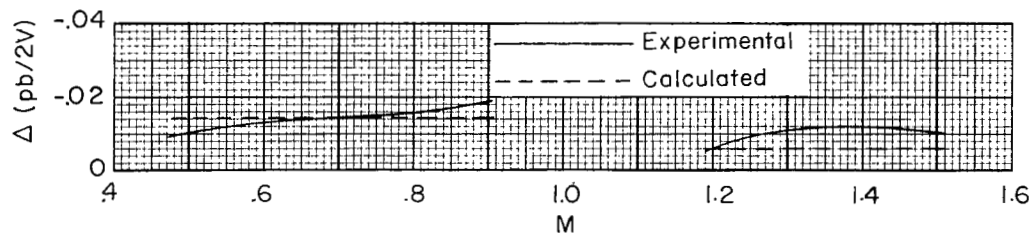Figure 7.- Effect of raising the horizontal tail 0.400c_r above the center line.
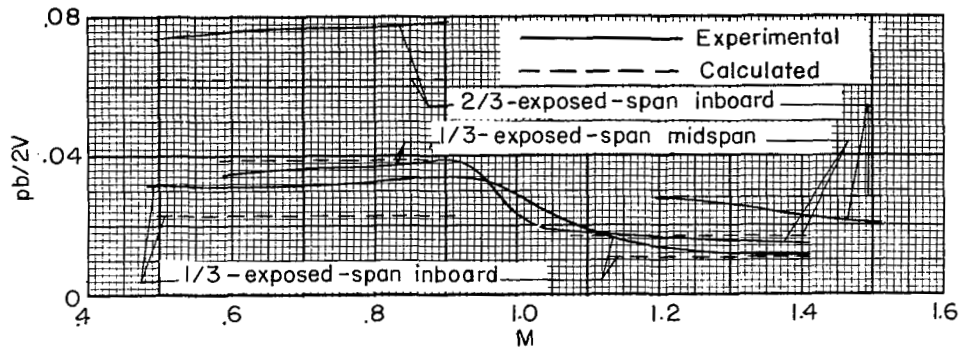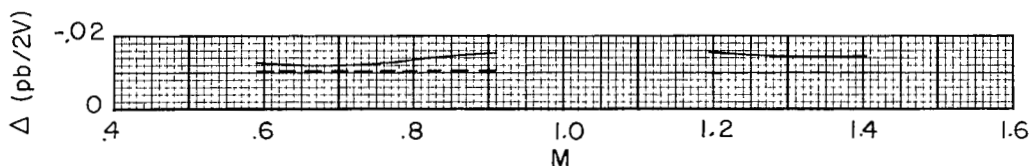
(a) No tail.
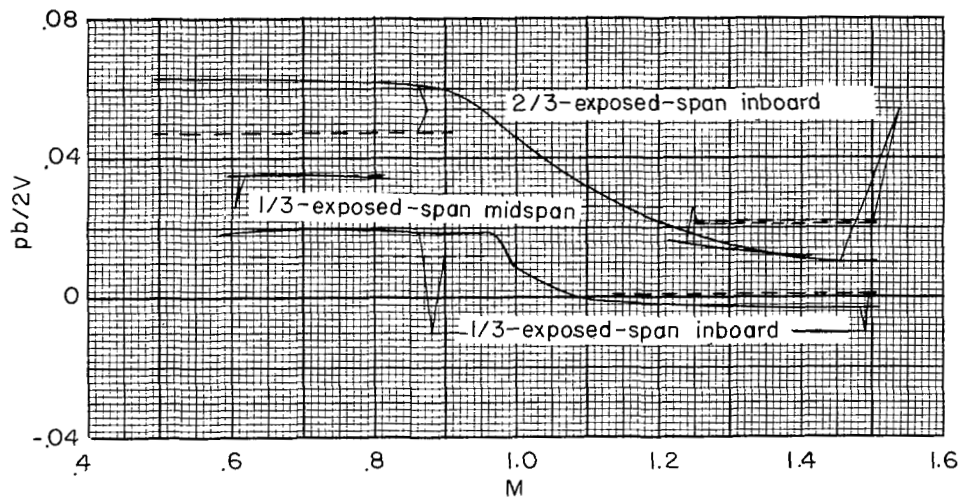
(b) Tail on center line.
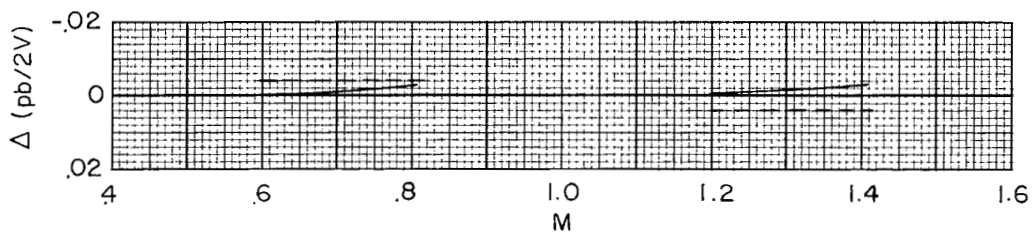
(c) Tail $0.400c_r$ above center line.

Figure 8.- Comparison of calculated and experimental data.
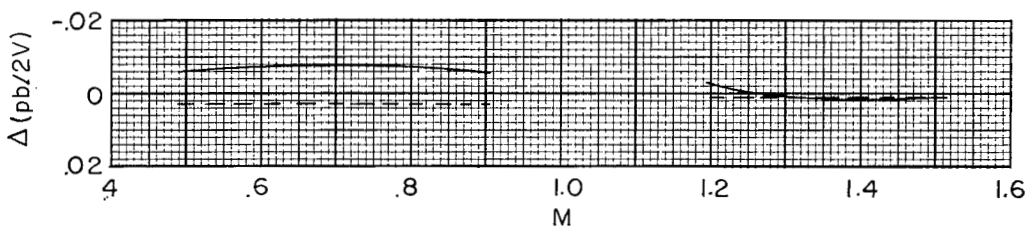
2/3-exposed-span inboard aileron

1/3-exposed-span inboard aileron

1/3-exposed-span midspan aileron

(a) $\Delta(\mathrm{pb}/2\mathrm{V})$ due to addition of tail surfaces.

2/3-exposed-span inboard aileron

(b) $\Delta(\mathrm{pb}/2\mathrm{V})$ due to changing horizontal-tail location.

Figure 9.- Variation of change in pb/2V due to addition of tail surfaces and due to change in horizontal-tail location with Mach number.